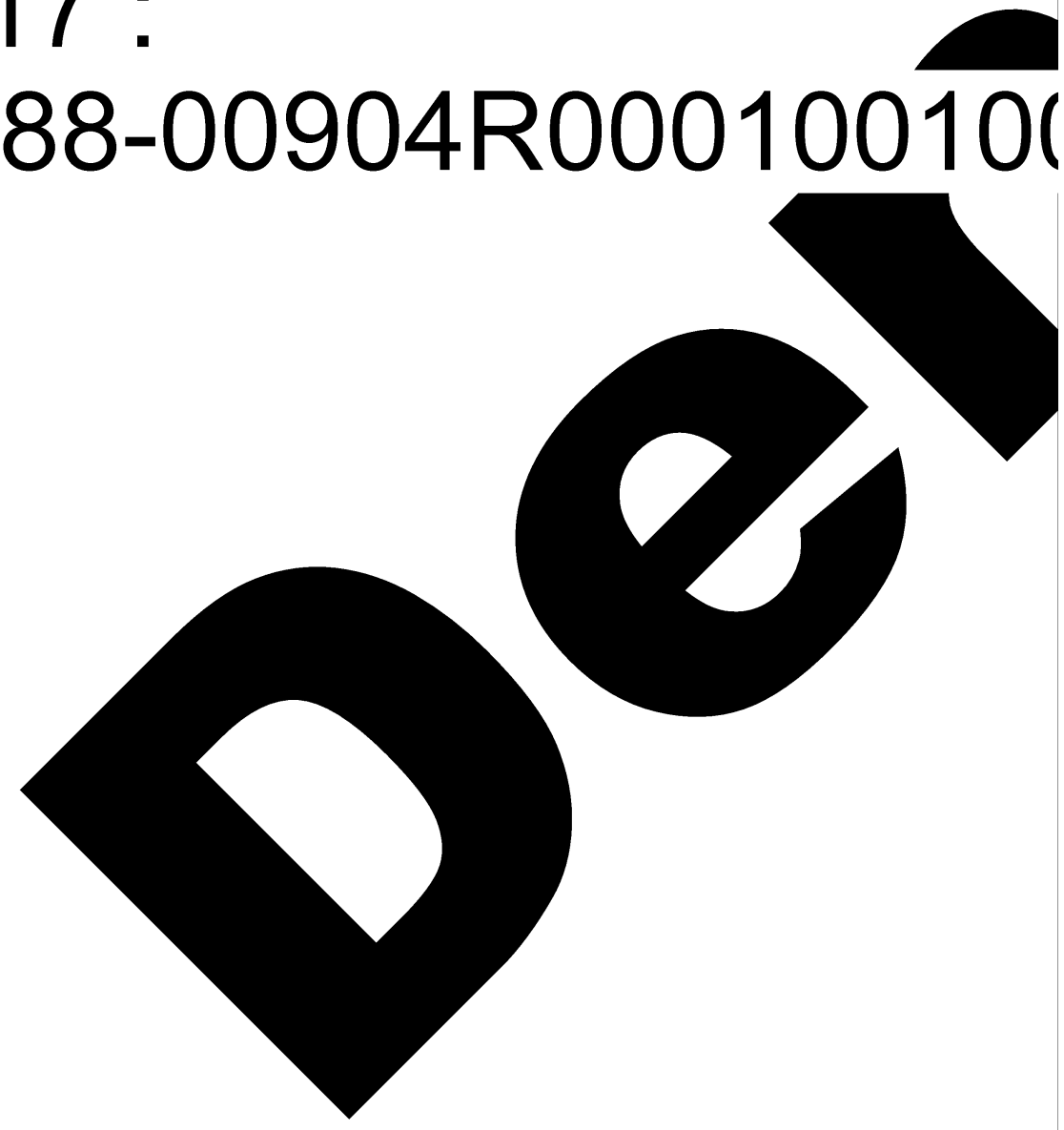

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QUANTITATIVE INVESTIGATIONS OF ATMOSPHERIC MOTIONS BY MEANS OF RADIOACTIVE TRACERS

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Introduction. The use of radioactive isotopes in meteorological investigations as air mass, cloud element and precipitation marks was widely discussed in the literature (see for example [1]). Used as such tracers, natural radioactive nuclides (radon, thoron and their decay products) arriving into the atmosphere from the ground, or produced there by cosmic rays, possess a number of advantages compared with artificial isotopes (nuclear explosion products). Sources of natural atmospheric radioactivity are relatively well studied. They are approximately stationary and so located, that transport of isotopes in the troposphere and lower stratosphere occurs both - upward (radon, thoron and their decay products) and downward (cosmic-ray-produced isotopes). This permits besides the quantitative study of air mass motions to estimate parameters of a series of atmospheric processes.

In the present paper a series of such investigations, based on measurements of radon and its decay product contain in air and precipitation are summarized. These isotopes are used for estimating vertical turbulent diffusion parameters in the lower troposphere (§1) in the stratosphere (§2) and also the rate of exchange through the tropopause or between the stratospheres of both hemispheres (§2). In § 3 these isotopes are used for the determination of washout rate of radioactive aerosols from the troposphere, and in § 4 they are applied together with some artificial isotopes for qualitative synoptic investigations.

§ I. Estimation of the vertical turbulent diffusion coefficient from the vertical profile of radon and its short lived decay product concentration

For the determination of K_z from the measured vertical concentration distribution of Rn, or of its decay products, a theoretical formula is usually developed containing K_z as a parameter. The value of K_z is then estimated from the condition for a best coincidence of the theoretical and measured concentration distribution [1].

In the ground atmospheric layer, with the radon source assumed to be a uniformly and continuously emanating plane, the problem of developing a theoretical formula for the vertical volume concentration distribution may be considered one-dimensional and stationary. Under certain boundary condition, the solution of the equations for turbulent diffusion Rn gives the following expressions for the above considered distributions depending on the law governing the K_z variation with altitude z [2,3,4]:

a) $K_z = \text{const}$; $\quad q(z) = q_0 \exp\left(-\sqrt{\lambda / K_z}\, z\right)$; /I.1/

b) $K_z = k_1 z^{1-n}$; $\quad q(z) = A E z^{m/2} K_{1-m}\left(\frac{m}{2}\sqrt{\frac{\lambda}{k_1}\, z^m}\right)$ /I.2/

when: $m = (2-n)^{-1}$; $\quad A = 2m^m \Gamma^{-1}(m)\, \lambda^{\frac{1-m}{2}} k_1^{\frac{1+m}{2}}$;

c) $K_z = \begin{cases} k_1 z, & z < H \\ k_1 H, & z \geq H \end{cases}$; $\quad q(z) = E\,\frac{2(1+NK_0(x))}{Nk_1}$, $z < H$ /I.3/

d) $K_z = \begin{cases} K_1 = \text{const}, & z < H \\ K_2 = \text{const}, & z > H \end{cases}$; $\quad q(z) = B \exp\left(-\sqrt{\frac{\lambda}{K_2}}\, z\right)$, $z > H$

$$q(z) = B e^{-\sqrt{\frac{\lambda}{K_1}}\, z}\left(1 - \frac{\sqrt{K_2} - \sqrt{K_1}}{\sqrt{K_2} + \sqrt{K_1}}\, e^{2\sqrt{\frac{\lambda}{K_1}}(z-H)}\right), \quad z < H \qquad /I.4/$$

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The following notation is used here: λ – radioactive decay constant; E – exhalation rate: $q_0 = E/\sqrt{\lambda K_z}$;

$N = [I_0(x_H) - I_1(x_H)] / [K_0(x_H) - K_1(x_H)]$; $K_\nu(x)$, $I_\nu(x)$ are modified Bessel functions: $x = 2\sqrt{\lambda z / k_1}$; $x_H = x|_{z=H}$;

B – an arbitrary constant: $0 < n < 1$ and depends on the ground layer stratification.

By use of these formulae the value of K_z is estimated from the radon concentration ratio at two levels, or from the ratio of radon concentration at one level to the exhalation rate E [1].

For the ground layer of the atmosphere the data of k_1 (value of K_z at the I m level) are given in Table I for the ground inversion conditions and for H=10 m. For comparison meteorological estimates of k_1 are also given in Table I. The ratio $q(1m)/E$ as a function of k_1 is expressed in Fig. 1 as result of measurements under convection conditions and of calculations by means of formula /I.3/ for H=40 m. Good qualitative agreement between experimental and theoretical data was obtained in both cases, although sometimes essential quantitative disagreement was observed.

In the boundary layer of the atmosphere we carried $\sqrt{Rn}$ concentration measurements at seven levels of the meteorological tower in the layer 0-300 m. The estimates of K_z obtained by means of formula /I.4/ under ground inversion conditions are given in Table II [6].

In the free troposphere the aircraft measurements of vertical profiles of short - lived radon daughters in different regions of the U.S.S.R. under the different meteorological conditions allowed to obtain estimates of K_z by means of formulae /I.4/ and /I.1/. Some of them are given in Table III.

Systematic observations of Rn and its short-lived decay product concentration distribution are useful not only for estimating K_z, but also for studying other meteorological processes, such as genesis development and destruction of inversions, development of convection streams, etc. Average exhalation rates for regions with linear dimensions of 1-3 thousand km were estimated by means of radon concentration vertical profile integration in the troposphere. In different regions of the U.S.S.R. these values vary from 0.9 to $8.0 \cdot 10^{-13}$ cu/m^{2}sec.

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We calculated the Rn concentration vertical profile distortion in the ground layer of the atmosphere, caused by the spatial inhomogenity of exhalation rate taking into account the average wind speed and for $K_z = k_1 z^{1-n}$. For the doubling of Rn concentration at the 1 m level over the leeward boundary of the high exhalation rate zone with $E^* = IOE = 2 \div 4 \cdot IO^{-12}$ cu/m^2 sec the linear dimension L of this zone should be L~1 km, for the same effect at the 100 m level : L ~ 50 km. Thus, with increasing altitude the small inhomogenities in E are rapidly smoothed out.

§ 2. Estimates of average exchange parameters in the stratosphere from its RaD (Pb^{210}) content measurements

The method of determination of the vertical turbulent diffusion coefficient K_z propozed in § 1, is applied here for estimating the K_z value in the lower stratosphere. For this purpose the mean mouthly concentrations of Pb^{210} (RaD) - long-lived isotope of radon decay chain with $T_{1/2}$ = 22,3 years was used. These concentrations were obtained by aircraft measurements at latitudes 70°N, 35°N, 10°N, 40°S and at levels: 4,6; 7,6; 12; 15; 18 and 20 km in May 1960-61 and in November 1960 [7] (Fig. 2).

The mathematical problem of constructing a vertical profile of the Ra D concentration in the upper troposphere and lower stratosphere may as a first approximation be considered stationary and one dimensional, since as seen from Fig. 2 at the tropopause level and higher this concentration was almost independent of latitude and was decreasing with altitude about equally during both months of observations.

For the stationary model of the atmosphere, consisting of the following layers: 1-the lower troposphere (the layer of aerosols washout by clouds and precipitation); 2 - the upper troposphere and 3 - the stratosphere, integration of a system of turbulent diffusion ordinary differential equations with suitable boundary conditions gives the following expression for the concentration c (z,w) per air mass unit of Ra D atom fraction, which is connected in the lower stratosphere with aerosols having a gravitational velocity w:

$$c(z,w) = F \exp\left[\beta (z - h_T)\right]; \quad z > h_T, \qquad (2.1)$$

where F (w,....) and β (w, K_z ....) are independent of z; $z = h_T$ is the tropopause height.

It can be assumed that the distribution in the stratosphere of the number of aerosol particles n(r) by their radii r has a density

$$dn/d\ln r = A_k r^{-\varkappa_k}; \quad k = 1,2, \tag{2.2}$$

where: A_k =const., $\varkappa_1 = 0$ for Aitken nuclei with radii of the order of $r_0 = 10^{-2}\mu < r < r_1 = 10^{-1}\mu$; $\varkappa_2 = 3$ for large particles (Junge sulphate particles) having $r_1 < r < r_2 = 1,0\mu$ [7,8]. Assuming that the average number of RaD atoms per aerosol particle is about Br^m (B = const. and $1 < m < 3$), the following expression of the summary RaD concentration over all fractions of the stratospheric aerosol is obtained:

$$C(z) = \int_{w_0}^{w_2} c(z,w)\, dQ^{(m)}; \quad Q^{(m)}(r_0, r) = \int_{r_0}^{r} Br^m \frac{dn}{dr}\, dr. \tag{2.3}$$

The density $dQ^{(m)}/dr$ or $dQ^{(m)}/dw$ of distribution having a sharp maximum, corresponding to $r = r_1$, $w = w_1$, the assumption of

$$C(z) = \exp[\beta_*(z - h_T)] \int_{w_0}^{w_2} F \frac{dQ^{(m)}}{dw}\, dw = \exp[\beta_*(z - h_T)]\, \overline{F},$$

$\beta_* = \beta_{w=w_1}$ may be made with sufficient accuracy.

From the average values of β^*, which are determined from the ratio of RaD concentrations, measured at two stratosphere levels, values of K_z, shown in Table IV are obtained for $r_1 = 0,03\mu$; $0,3\mu$ and $0,1\mu$ as the range of variability and the most probable value of r_1 respectively [8].

Table IV shows that maxima values of K_z are observed in spring in temperate latitudes of both hemispheres, and the minima ones - in the equatorial zone. This corresponds to the existing qualitative picture of seasonal and latitudinal variatious of K_z in the stratosphere, which is obtained from the observations of the nuclear explosious debris propagation [7]. The order of magnitude of K_z is close to the estimates obtained in [7], though its value is a little lower.

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The values of K_z in troposphere and stratosphere obtained here and in § I together with the estimates of the average radon exhalation rate E and above mentioned RaD concentration data in a free atmosphere permits to find the average rates of exchange through the tropopause and between the stratospheres of both hemispheres. Fig.2 shows that the meridional distribution of RaD concentration at the 4,6 km level is similiar to the land area distribution over the entire zonal belt area. The land area in the northern hemisphere being three times that of the southern one, Rn enters the stratosphere mostly in the northern hemisphere producing there RaD. The comparatively long residence time of RaD in the stratosphere leads to the levelling of its content in both hemispheres and a summary withdrawal of RaD from the southern hemisphere stratosphere occurs.

The annual mean values of all the Rn and RaD fluxes were calculated as arithmetic means of their values for May and November in extratropical latitudes. Values of K_z and these fluxes obtained from measurements in latitude 70°N are considered to be valid for the belt 90° - 50°N, those from latitude 35°N - for the belt 50°-20°N, and from 40°S - for the belt 20-90°S. The fluxes of Rn and RaD through the tropopause of belt 20°N - 20°S are considered to be negligibly small because of the strong stability of the tropical stratosphere (this is supported by observations of the stratospheric fallout of nuclear bomb debris [7]).

The following notation is introduced here: I_N (I_S) - annual mean number of RaD atoms in the stratosphere of the northern (southern) hemisphere (in the layer between the tropopause h_T and h_T + 8 km levels);

$\Pi^{(Rn)}_{T\to N}$ ($\Pi^{(Rn)}_{T\to S}$) - annual Rn atoms influx in the stratosphere of northern (southern) hemisphere;

$\Pi^{(RaD)}_{N}$ ($\Pi^{(RaD)}_{S}$) - annual 3,1% decrease of RaD in the stratosphere of the northern (southern) hemisphere due to radioactive decay;

$\Pi^{(RaD)}_{N\to S}$ - annual summary flux of RaD from the stratosphere of the northern to the stratosphere of the southern hemisphere;

$\Pi^{(RaD)}_{S\to T}$ - annual outflux of RaD from the stratosphere to the troposphere of the southern hemisphere.

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From the obvious balance equations for the stratosphere of the : a/ northern hemisphere; b/ southern hemisphere

a) $\Pi^{(Rn)}_{T\to N} - \Pi^{(RaD)}_{N} = \Pi^{(RaD)}_{N\to S}$ *) ; b) $\Pi^{(RaD)}_{N\to S} + \Pi^{(Rn)}_{T\to S} - \Pi^{(RaD)}_{S} = \Pi^{(RaD)}_{S\to T}$

and for the three groups of the K_z values given in Table IV the values of these fluxes are obtained and listed in Table V. The values of

$$\tau_N = I_N \Big/ \Pi^{(Rn)}_{T\to N} \; ; \quad \tau_S = I_S \Big/ \Pi^{(RaD)}_{S\to T} \; ; \quad \tau_{N\to S} = I_N \Big/ \Pi^{(RaD)}_{N\to S}$$

residence time of the RaD atoms in the stratospheres of both hemispheres are also given in Table V. These values are obtained under the assumption that as a first approximation the exchange between these reservoirs obey first order kinetics laws . τ_N, τ_S and $\tau_{N\to S}$ are close to one anothr and also to the known estimates of air mass exchange rates between the troposphere and stratospheres of both hemispheres [7,9].

The last column of Table V shows, that the annual increase of RaD atoms in the stratosphere of the southern hemisphere from the decay of Rn of this hemisphere is about 20% of their influx from the stratosphere of the northern hemisphere.

§ 3. Estimation of the mean removal rate from the troposphere of natural radioactive aerosols by clouds and precipitations

The simultaneous measurements of Rn and its long-lived decay product content in the ground-level air and in the precipitations are used for the determination of the mean removal rate of these substances from the atmosphere. This quantity characterizes the removal rate of aerosols being carriers of the isotopes under consideration [1] .

The average residence time τ of natural radioactive aerosols in the atmosphere is usually determined by the disturbance of the radioactive equilibrium relation between the concentrations of radon decay chain elements measured in ground air and in precipitation

*) It can be shown that no significant amount of RaD atoms enters the stratosphere from the troposphere.

from the following equality:

$$\lambda_{i-1} q_{i-1} = (\lambda_i + \Lambda_i) q_i \qquad (3.I)$$

in which q_i - is the concentration of the chain isotope expressed in atoms per unit volume, λ_i - its radioactive decay constant, $\tau_i = \Lambda_i^{-1}$ - average residence time of element in the atmosphere [I]

Till recently the value τ was incidentally estimated by means of formula (3.I) in different points of the globe. In 1959-1960 near Moscow an attempt was made to find the seasonal variations of τ from measurements of radon and RaD concentration in the ground air layer. The obtained results are given in Table VI. No distinct seasonal variations of τ have been detected, but the minimum values observed in February, September and October, should be mentioned.

The use of formula (3.I) for estimating the average removal rate of radioactive aerosols gives unsatisfactory results, since the obtained estimate describes quantitatively the resulting effect produced by different processes removing aerosol from different atmospheric layers II . Thus the residence time of different isotopes estimated by means of formula (3.I) appears to be different, what is obviously not true for the aerosols - carriers of these isotopes. We proposed the model which permits as a first approximation to find a separate contribution to τ from two fundamental processes: turbulent aerosol diffusion in the troposphere and aerosol washout by clouds and precipitation in the lower troposphere [II] .

In the proposed model a horizontally homogeneous twolayer troposphere was assumed, having a single constant vertical turbulent diffusion coefficient K_z throughout the entire troposphere. It is further assumed that in the lower layer stationary removal of radioactive aerosol occurs, following the first order kinetics law and having a constant average washout coefficient σ throughout the entire layer. As a first approximation the washout of the short-lived isotopes was not taken into account and they were considered to be in radioactive equilibrium with radon.

Four isotopes are thus considered here: 0) Rn (Rn^{222},

$T_{I/2}$ = 3.85 days); I) RaD (Pb^{210}, $T_{I/2}$ = 22.3 years); 2) RaE (Bi^{210}, $T_{I/2}$ = 5.0 days) and 3) RaF (Po^{210}, $T_{I/2}$ = 138 days).

Vertical distribution of volume concentration $q_i(z)$ (i = 0.1, 2, 3) of these isotopes is found in [II] by solving a system of ordinary differential equations of turbulent diffusion with suitable boundary conditions at ground level ($z = 0$), $z \to \infty$ and at the boundary separating both layers ($z = h$). The specific activity ratio for a pair of decay chain isotopes at a level $z < h$ expressed by:

$$\lambda_k q_k(z) / \lambda_i q_i(z) = \chi_i^{(k)}(z, \zeta, \varkappa), \quad k > i, \tag{3.2}$$

was found to depend on radioactive decay isotope constants λ_i and on dimensionless parameters:

$$\zeta = \sigma/\lambda_0 \; ; \quad \varkappa = h\sqrt{\lambda_0 / K_z} \, . \tag{3.3}$$

The value of $\chi_i^{(k)}$ is determined from measurements of the isotope concentration ratio in the ground layer and in precipitation. The following two extreme assumptions are made in the last case: A) the specific isotope concentration ratio in rain water was equal to the average concentration ratio in air over layer $0 < z < h$:

$$\chi_i^{(k)}(\zeta, \varkappa) = \lambda_k Q_k / \lambda_i Q_i \; ; \quad Q_i = \frac{1}{h} \int_0^h q_i(z)\, dz \, . \tag{3.4}$$

This means that radioactivation of rain drops occurs about equally throughout the entire washout layer. B) The ratio of the specific isotope concentrations in rain water was equal to the ratio of these concentrations in air a level of $z = h$: $\chi_i^{(k)}(h, \zeta, \varkappa)$, i.e. radioactivation of rain drops occurs mainly in the upper part of the cloud layer [II] .

The calculated graphs, given in [II] show the dependence of the dimensionless washout coefficient $\zeta = \sigma/\lambda_0$ on the ratio of specific activities of RaD/Rn, RaF/RaD, RaE/RaD in ground level air $\chi_i^{(k)}(z = 0)$ in precipitations: $\chi_i^{(k)}$ (case A), $\chi_i^{(k)}(z = h)$ (case B) for a number of parameter values. From these graphs and published results of such measurements of these isotopes specific activity ratios values of ζ were determined. The values of ζ obtained for the

same value of $\varkappa$ for different isotope pairs appeared to be close to one another and the values of $t = 1/\sigma = 5.56/\xi$ (days) - close to the residence time of aerosols in the lower troposphere (I-IO days), calculated by means of a formula of the form (3.I). With measured RaE/RaD ratios and the assumption B) the values of σ obtained for all values of $\varkappa$, are unreally overestimated and coincide with the estimates of its "instantaneous" values during the rain [I2].

The single-valued determination of $\varkappa$ and ξ requires simultaneous concentration measurements in ground air for at least three of the above mentioned isotopes. The results of such measurements carried out in Freiburg (FRG) in summer of I957 and in Moscow district at the end of I963 together with the corresponding values of $\varkappa$ and ξ are listed in Table VII. The obtained values of σ are of the same order of magnitude as the estimates of the radioactive aerosol washout coefficient made by different methods II, I2.

Knowledge of the average radon exhalation rate E from soil in the region during the ground concentration measurements permits to estimate the remaining parameters of the model - K_z and h. In the cases listed in Table VII these estimates were obtained from the relation $q_0(0) = E/\sqrt{\lambda_0 K_z}$ following from (I.I) and from formula (3.3), with the average value of E = 40 atoms/cm^{2}min They are for Freiburg - K_z = 25 sq.m/sec; h = 3.8 km; for Moscow district - K_z = 4.2 - 8.3 sq.cm/sec; h = 0.7 - I.I km.

These are very rough estimates since in the assumed model the decrease of K_z with decreasing z in the ground layer, where measurements were carried out, was not taken into account and the measurements of E were inaccurate and quite insufficient in number (§ I).

Estimates of washout coefficient σ of radioactive aerosols containing RaD almost coinciding with the above estimates, were obtained for a three-layer model of a horizontally homogeneous stationary atmosphere described in § 2. Making use of the estimates of the vertical turbulent diffusion coefficient K_z in the troposphere obtained in § I, it is possible to find unambiguously rather close limits within which the washout coefficient σ and the height of the washout layer h should lie, in order to obtain the measured value of the RaD concentration at the tropopause level h_T.

For these concentration values given in Fig. 2 at measurement points, in latitudes 70°N and 35°N, the following values are obtained: $\sigma = 3.2 \div 4.4 \times 10^{-6}$ sec^{-1}) and $h = 7 \div 9$ km. The latter value corresponds to the average level at which the upper cloud edge of the upper cloud layer is situated, which thus also takes part in the removal process of aerosol from the troposphere.

§ 4. The use of radioactive isotopes in synoptic investigations

Radioactivity of air and precipitations can be used in synoptic investigations of vertical and horisontal transport, interaction and transformation of air masses. The problem to be considered and the conditions of the study determine the choice of isotopes (or their combination) as a tracer. It is convenient f. inst. to use isotopes of stratospheric origin (natural cosmogenic isotopes, or nuclear bomb debris during periods free of nuclear weapon tests) in the study of stratospheric air transport into the troposphere. Transfer of tropospheric air into the stratosphere can be determined by the change of radon and its decay product content in the stratospheric air samples.

The gross beta activity of fission products was chosen as the stratospheric air tracer in the study of synoptic conditions for stratospheric a ir transfer into the troposphere. The daily fields of gross beta activity of artificial origin in ground level air over a wide territory in temperate latitudes were compared with the 300 mb isobaric surface charts and weather charts. We consider the suddenly appearing and sharply outlined regions of high level ground air radioactivity as having been formed by air masses of recent stratospheric origin so the conditions for their appearance being favourable for the penetration of stratospheric air into the lower troposphere.It was found that: I) In an overwhelming majority of cases the "radioactive spots" near the ground appeared behind the cold fronts in the rear of the well developed cyclones, 2) The appearence of these "spots" was often accompanied by the formation of a ridge in the lower troposphere; 3) During the following days such a "spot" was usually moving along the ridge periphery to the south-western then western and north-western directions up

to the moment when conditions for condensation and ascending motions arose; The above considered synoptic situation was usually accompanied in the upper troposphere by an intersive trough of a sharp profile and very high wind velocities on its periphery; 5. As a rule the length of such troughs was about several thousand kilometres, but ground level radioactive "spots" most often appeared under the southern part of the trough, where on its axis, to the left of the jet steam a sharp decrease of baric gradients and wind velocities was observed. In many cases in this part of the trough formation of a cut-off upper cyclone occured.

The revealed conditions of the atmospheric process development in the lower and upper troposphere under which penetration of stratospheric air into the ground layer takes place, permitted not only to understand better the mechanism of this transfer and of the radioactive fallout patterns but also to come near to forecasting the appearance of high radioactivity level regions in the surface air.

Different radioactive characteristics of the ground level air (Rn, RaD, Sr^{90} and gross beta activity concentrations) obtained in summer 1960 at a research ship on its passage from Odessa to Vladivostok combined with the results of synoptic studies permitted on the one hand to show the influence of atomospheric processes on global distribution of radioactive isotopes in the tropical regions and on the other hand to refine the analysis of the atomospheric processes from radioactivity characteristics. The high levels of long-lived fission product concentration to the north and low ones to the south from the tropical convergence zone, connected with the axis of the soutern Asia summer depression (Fig.3). show its role as a barrier to the interlatitude air mixing.

The most significant increase in radioisotope concentration in the equatorial zone coincided with the change in wind direction when the ship passed from the air current system of the northern hemisphere into that of the southern hemisphere. These increases and the observed Weather conditions permitted to assume the existence in the equatorial region of the Indian ocean of a second convergence zone, separating the low radioactivity level air of the northern part of the Indian ocean from the higher radioactivity level air arriving from the southern hemisphere (see fig.3). During

the period under consideration in the southern (winter) hemisphere synoptic conditions existed for the penetration of stratopheric air into the lower toposphere over the Australian region and for its further displacement over the Indian ocean towards the equatorial zone.

Observations of fresh fission product spreading carried out in fall and winter of I96I-62 at a research ship in the troposphere of equatorial Pacific permitted to estimate its meridional velocity.

The value of this velocity (I,0 km/hour) was found to be close to its estimate I,3 km/h, obtained from the observations carried out on the 80°W meridional network of stations for the same period [I3] .

Conclusion

From the above given brief survey of meteorologic investigations by means of radioactive isotopes the breadth and fruitfulness of this new trend in meteorology can be seen. It occupies an important place in the new branch of atmospheric physics-nuclear meteorology.

Further developments in this direction require a sharp increase in the number of measurements of natural radioactive isotopes particularly in a free atmosphere during different seasons in different geographic regions, as well as a close cooperation of physicists and meteorologists in obtaining and interpreting the results of such measurements.

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Table I. Vertical turbulent diffusion coefficient at I m level k_1 (m^2/sec) for ground inversion conditions

Date and time of measurements	$\frac{q_0(1m)}{E}$ (sec/m)	k_1 from (I.3)	Meteorological estimates of k_1
I3/VIII 2Ih 30m	$I.7xIO^3$	0.0I	0.003
I4/VIII Ih 00m	$2.9xIO^3$	0.005	0.009
I4/VIII 5h 00m	$6.4xIO^3$	0.0008	0.00I5
I5/VIII 20h 30m	$I.7xIO^3$	0.0I	0.0024
I6/VIII Oh 00m	$4.2xIO^3$	0.00I	0.0024
I6/VIII 4h 30m	$6.0xIO^3$	0.0008	0.00I5

Table II. Vertical turbulent diffusion coefficient K_2 (m^2/sec) in layer 0-300 m and under ground inversion conditions

Date and time of measurements		inversion altitude (m)	K_1	K_2	ΔT in inversion layer (^oC)
6/IX	22-23h	I00	0.003 /to 25m/	-	-4
I0/VIII	2I-22h	75	0.04	3.0	-7.3
3/IX	20-2Ih	75	0.0054	-	-2
2I/IX	I9-20h	75	0.05I	0.48	-2.9

Table III. Vertical turbulent diffusion coefficient K_2 (m^2/sec) in the troposphere from aircraft measurements

Meteorological conditions	Region of measurements	Levels of measurements (km)	Number of measurements	K_2 values average	K_2 values variation range
Stable stratified	U.S.S.R.	0,05-I,0	I2	3	0,4-30
troposphere	territory	I,0-5,0	I2	50	20-I000
In the convection layer	Europian part of USSR	0,05-I,5	9	-	50-3000
-"-	Middle Asia	0,05-4,0	II	-	$50-IO^4$

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Table IV. Turbulent diffusion coefficient K_z of natural radioactive aerosols in the stratosphere (m^2/sec)

Latitude	r_1 =0.03 μ		r_1 = 0.1 μ		r_1 = 0.3 μ	
	May	November	May	November	May	November
70°N	0.087	0.045	0.I8	0.II	0.38	0.27
35°N	0.I3	0.068	0.24	0.I4	0.47	0.22
I0°N	0.044	0.044	0.I2	0.I2	0.29	0.29
40°S	0.054	0.I3	0.I3	0.22	0.30	0.46

Table V. Rn and RaD atom fluxes ($I0^{22}$ atoms/year) and their average residence time τ(years) in the stratospheres of the northern and southern hemispheres

$I'_N = 6.3\ 10^{22}$ atoms ; $\Pi_N^{(RaD)} = 0.20$; $I_S = 6.1\ 10^{22}$ atoms , $\Pi_S^{(RaD)} = 0.19$

r_1 (μ)	$\Pi_{T\to N}^{(Rn)}$	τ_N	$\Pi_{N\to S}^{(RaD)}$	$\tau_{N\to S}$	$\Pi_{T\to S}^{(Rn)}$	$\Pi_{S\to T}^{(RaD)}$	τ_S	$\tau=\frac{\tau_N+\tau_S}{2}$	$\Pi_{T\to S}^{(Rn)}/\Pi_{N\to S}^{(RaD)}$
0.3	4.I	I.6	3.9	I.6	0.8	4.5	I.3	I.4	0.22
0.I	3.0	2.I	2.8	2.3	0.6	3.2	I.9	2.0	0.22
0.03	2.2	2.8	2.0	3.I	0.5	2.3	2.6	2.7	0.22

Table VI. Monthly average Rn and RaD concentration in ground layer of the atmosphere and value of τ from measurements in Moscow district (I959-I960)

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Rn concentration in $I0^{-I0}$ cu/m^3	I.2	0.6	0.7	0.4	0.3	0.4	0.6	0.8	0.6	I.0	I.0	I.6
RaD concentration in $I0^{-I5}$ cu/m^3	II.6	3.9	8.7	5.0	4.7	4.2	7.6	8.3	4.6	7.3	20.4	I2.5
τ (days)	I.I	0.8	I.4	I.5	I.8	I.2	I.4	I.2	0.9	0.8	2.3	I.0

Table VII. Washout coefficient δ and average residence time τ in the atmosphere of long-lived radon decay products

Locality and time of measurements	Ratio of activities		τ (days) for ratio		$\varkappa$	ζ for ratio		δ sec^{-1}
	$\frac{RaD}{Rn}$	$\frac{RaE}{RaD}$	$\frac{RaD}{Rn}$	$\frac{RaE}{RaD}$		$\frac{RaD}{Rn}$	$\frac{RaE}{RaD}$	
Moscow district, X-XI-63 /7/ x)	$I.IxI0^{-4}$	0.47	I.3	8.4	0.37	9.5	9.I	$I.9xI0^{-5}$
Moscow district, XII-63 /4/ x)	$0.9xI0^{-4}$	0.32	I.0	4.5	0.70	6.3	2.2	$I.4xI0^{-5}$
Freiburg Summer 57 /39/ xx)	$I.9xI0^{-4}$	0.07	2.I	2I xx)	I.I	2.2	2.3 xx)	$4.7xI0^{-6}$

x) The brackets indicate the number of measurements used in averaging.

xx) These values are determined for the activity ratio RaF/RaD.

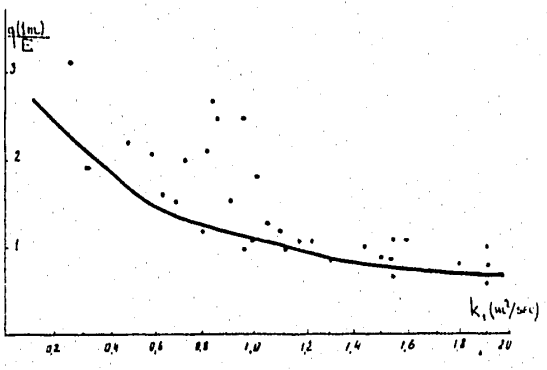

Fig.I. Calculated and experimental values of $\frac{q(Im)}{E}$ as functions of k_I (convection conditions).

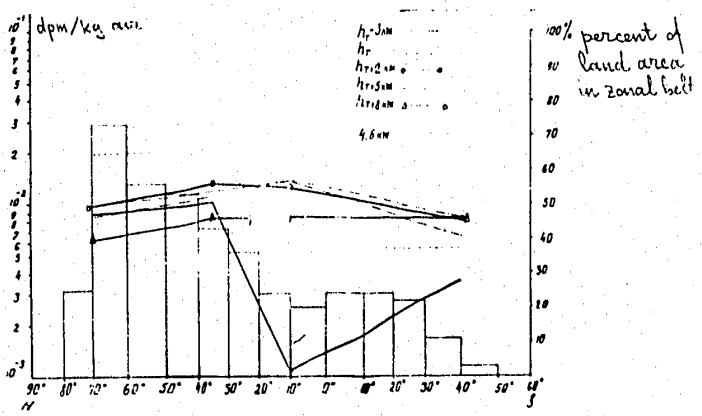

Fig.2. Meridional distribution of Ra D concentration (d.p.m.per kg of air) in May of I960-6I at levels: of 4,6 km; of the tropopause (h_T); of 3 km below the tropopause (h_T-3km); of 2,5 and 8 km above the tropopause (h_T+2km etc); and a hystogram of the land area percent in the zonal belt.

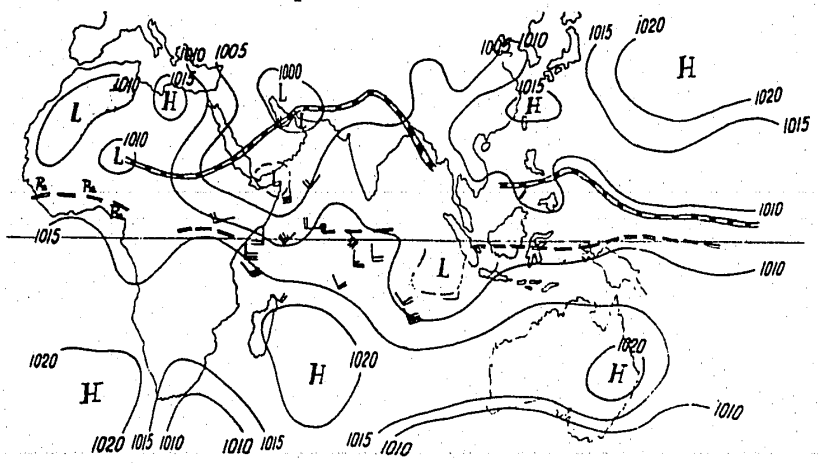

Fig.3. A synoptical chart on July I6 of I960 and the supposed situation of the second convergence zone (dotted line) in the equatorial region; ▬▬ - the dividing zone, connected with the South-Asia depression and • - the ship's situation.

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